International Journal For Technological Research In Engineering
Volume 6, Issue 11, July-2019 *ISSN (Online): 2347 - 4718*

A STUDY ON VARIOUS FACTORS AFFECTING DISCHARGE HEADWAY AT SIGNALIZED INTERSECTION UNDER HETEROGENEOUS TRAFFIC CONDITIONS

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ABSTRACT: Discharge headway is the headway between successive vehicles negotiating an intersection during the green time of signal operation. It is an important parameter in signal operations and analysis since estimation of parameters such as saturation flow and capacity of an intersection depend on it. Although there have been several studies on discharge headway in homogeneous traffic conditions, there are only a few studies on discharge headways in heterogeneous traffic. This study examines the factors affecting discharge headway under heterogeneous traffic conditions which is characterized by mixed vehicle composition and lack of lane discipline. A new method to measure headways in such cases is proposed here.

To get individual vehicle headways, each lane is divided into multiple strips. The width of a strip is approximately equal to the width occupied by a motorcycle. The headways of vehicles in each strip are measured separately and used for analysis. Data collection for the study was carried out at signalized intersections in Sirnagar (Jammu and Kashmir), India. Data was collected for one approach at all intersections. From the data collected, headways of individual vehicles were measured. Linear mixed effect regression was used to model discharge headway. The effect of vehicle length, engine capacity of vehicle, lateral position on roadway, and green time on discharge headway were modeled. From the regression analysis, it was found that all these factors had significant impact on discharge headway. The discharge headway model proposed in this study could be used for obtaining saturation flow rates and capacity at signalized intersections under heterogeneous traffic conditions also.

I. INTRODUCTION

Intersections are a vital part in an urban transportation network. The main traffic parameters at a signalized intersection include discharge headway, saturation flow, and capacity. Among these, discharge headway is an important one since it is used to determine other parameters such as saturation flow and start-up lost times at intersections. These two parameters have in turn been used in determining optimal signal timings. Inaccuracies in discharge headway values would lead to non-optimal signal operations. Several studies have been carried out on discharge headway – on factors affecting it, on distribution followed by headway, and on determination of other traffic parameters from discharge headway. Most of these studies were done for homogeneous traffic which is characterized by lane disciplined movement and cars were the predominant vehicle type present. Several Asian countries including India have heterogeneous traffic lacking in lane discipline. This study focuses on understanding discharge headway of heterogeneous traffic in underdeveloped countries were lane disciplined movement of vehicles is not predominant.

While discharge headway has been studied for over seven decades, even recently studies have examined fundamental questions such as the existence of a saturation headway (Radhakrishnan and Mathew (2011); Remias et al. (2013)). Heterogeneous traffic conditions and the absence of lane following provide significant challenges to the study of discharge headways. For example, consider a single lane with two motorized two-wheelers travelling side-by-side which is followed by a car. How would the headway for the car be defined? The traditional definition of headway as the time gap between successive vehicles in a lane cannot be applied here.

In this study the roadway width is divided into multiple strips. A strip is narrower than a lane just wide enough to accommodate no more than one two wheeler at a time. Headway is measured in each strip separately. Data is collected from three different intersections. At one of the intersections data is collected for morning and evening peak periods. Headway data shows significant variability. Regression models are developed for discharge headway with vehicle type, lateral position along the road width, and the green time period as explanatory variables. To better capture the variability of headway a mixed-effects model is also developed. The use of strips to more accurately and meaningfully measure headway is a fundamental contribution of the present work. This is also the first attempt, to the best of our knowledge, of developing a mixed-effects model for discharge headways using such parameters that include vehicle characteristics.

Need Of Study

Man was surely far away from guessing the serious trouble his wheel discovery, pooled with other inventions taking place through time, would bring about around 60 centuries later. Of course, both health and elusive life value put aside, the benefits of such a discovery have been far more important and transcendent to human advancement. The invention of the steam engine in the early XVIII century allowed for a number of trials with little success, of applying this source of power to selfpropelled road vehicles. French engineer Nicolas J. Cougnot successfully invented the first automobile using a steam engine in 1770 and by 1803, U. S. inventor Oliver Evans built the first self-propelled vehicle that traveled through the United States roadways. Its daily consequences are endured now for at least 10 decades in terms of crashes, delays and, more recently, pollution. The ever-growing consumption of a nonrenewable natural resource like oil, out of which gasoline and diesel, among other fuels are obtained, is also a concern.

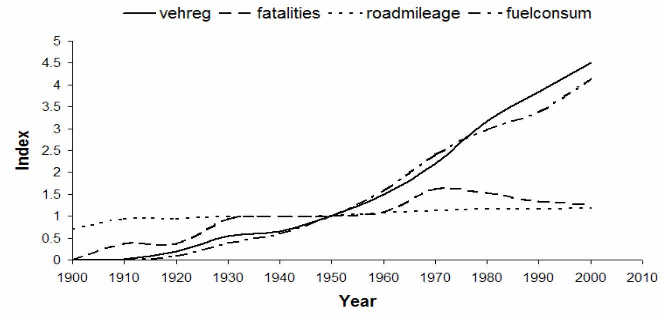


Figure 1.1 Growth rate of traffic Problems in India (MORTH)

But, how did this *traffic problem* start? At the beginning of the 20th century the number of vehicles was few and their relatively low speeds (barely above the animal-drawn ones') allowed that century's first decade to go by without major concern. Things were rather different in the following decades, though. From the outset, the mileage of existing roads was not enough for the number of vehicles that was rapidly growing year after year, and the conditions of such roads did not match with operating features of the fast automotive vehicle. As auto-makers incorporated higher speeds to their vehicles and the overall quantity of autos skyrocketed, consequences immediately appeared in the form of pitiable crashes and saturated roadways that were not built for such vehicles In past few decades emphases is laid on traffic studies as traffic is considered one of the key factor of development. And very much research is done on headways modeling, but the conditions prevailing in south Asian courtiers like India were traffic is heterogeneous or mixed , a very less study has done in this field. In order to find a relation between vehicle headway and other factors that affects the headway in mixed traffic conditions, a study was done to find the some major factors affecting the headway.
Also no such empirical formula has been put forward that can be employed to find the headway under heterogeneous traffic conditions. It was the need of hour to generate an empirical formula that can be employed to calculate the headway under mixed traffic conditions.

Objective Of study
The conditions prevailing in south Asian courtiers like India were traffic is heterogeneous or mixed, a very less study has done in modeling the discharge headway. In order to find a relation between vehicle headway and other factors that affects the headway in mixed traffic conditions, this study is done to find the some major factors affecting the headway.
This study is done in order to model a empirical relation between headway and distance from median, vehicle characters, green time and time of day

II. LITERATURE REVIEW

Discharge headway at a signalized intersection can be defined as the time interval between two successive vehicles on a lane crossing the stop line at an intersection during the green time. Greenshields et al.[6] (1947) was one of the first studies on discharge headway in which he reported average headways for the first five vehicles of the queue . Carstens[5] (1971) reported the average starting delay for vehicles in queue as 0.75 s and average headway spacing for straight moving cars as 2.29 s per vehicle. Moussavi and Tarawneh[12] (1990) conducted studies on departure headways at signalized intersections in Nebraska and concluded that departure headways show high variability for different intersections possibly because of the different traffic and geometric conditions prevailing there. They also came up with a set of values for departure headway of first seven queue positions. Bonneson[4] (1992) developed a model for discharge headway at signalized intersections based on driver reaction time, driver acceleration, and vehicle speed. His model showed that minimum discharge (saturation) headway is reached only after eighth or ninth queue position.
Al-Ghamdi[1] (1999) conducted a study on discharge headway at intersections in Riyadh, Saudi Arabia. He observed that it is not reliable to use discharge headway values from other countries in Saudi Arabia due to changes in factors such as driver behaviour and intersection geometry, and came up with average headway values for different queue positions. Several other studies have come up with distributions for discharge headways. Jinet al.[7] (2009) studied the departure headways at signalized intersections. They found that distributions of departure headways at each position in queue follow a log-normal distribution except the first one. A car-following model was also proposed to explain this behavior which can be used for intersection capacity analysis and traffic control. Liu et al.[9] (2011) introduced a hazard based model to analyze the first discharge headway of queuing vehicles. The model has been developed on the basis of data collected from Beijing and it was found that the first discharge headway is dependent on vehicle type and complexity of intersection and any other disturbance to the vehicle movement will further increase the discharge headway. Wu et al.[18] (2010) studied departure headway distributions. Their study revealed that for modeling headway data, log-laplace distribution model is suitable at free flow conditions and log-logistic model during peak hours. Yin et al.[19] (2009) also arrived at similar conclusion about fitting headway distributions to headway data for free-flow state and congested state. Their findings include that headway data follows log-normal distribution when traffic is in free-flow state and log-logistic distribution when traffic is congested. Rossi and Gastaldi[17] (2012) also studied about the distributions for time headway data for rural two lane two-way roads.
Few studies on saturation headway/flow carried out in India for heterogeneous traffic include those of Maini and Khan[11] (2000), Arasan and Koshy[2] (2005), and Arasan and Vedagiri[3] (2006). Maini and Khan[11] (2000) conducted a study on discharge characteristics of heterogeneous traffic at signalized intersections in two Indian cities – Baroda and New Delhi. They determined clearing speed of vehicles from intersection and concluded that clearing speed does not vary

significantly with vehicle type and vehicles move as a single platoon at intersection and those with higher performance are affected by those with lower performance. Arasan and Koshy[2] (2005) suggested a method for modeling heterogeneous traffic flow by simulation with vehicles of wide ranging characteristics. The model was validated and found to replicate traffic without lane discipline and could be used for further studies on heterogeneous traffic. Arasan and Vedagiri[3] (2006) applied a simulation model to estimate saturation flow to study the effect of road width on saturation flow under heterogeneous traffic conditions. It was found that there is a significant increase in saturation flow with increase in road width. Radhakrishnan and Mathew[14] (2011) proposed a methodology to develop saturation flow model based on dynamic PCUs. PCU values are determined by minimizing the difference between ideal and observed flows using Thiels coefficient as the objective function and then saturation flow model is developed by regressing saturation flow in vehicles against the percentage of each class of vehicle.

The first work on measuring lost times and saturation headways was done by Bruce D. Greenshields[6] in the mid-40's (Roess 1998). Available recording devices during that time demanded a several step process from field observation to final data transcription. Working with field data (2,359 observations from a signalized intersection in Hartford, Connecticut) that included left turn movements and heavy vehicles, and based on supplemental studies of equivalencies, his final findings refer to through movements and passenger cars only.

Mr. Greenshields demonstrated that headway between vehicles decreases at a lessening rate until after the fifth waiting vehicle enters the intersection, and that afterwards it tends to level out around 2.1 seconds; he also found that the extra time beyond these 2.1 seconds for the first 5 vehicles amounted to 3.7 seconds (Greenshields 1947).

In the process of preparing the 2nd edition of the Highway Capacity Manual, data from 1,100 signalized intersections collected during 1955 and 1956 it was found that a line of vehicles stopped by a traffic signal would rarely move away from the intersection at a rate greater than 1,500 vehicles per hour of green per lane, or vphgpl (h = 2.4 seconds). On the other hand, provided that the subject intersection is part of a perfectly-coordinated progressive signal system, then a capacity flow rate of 2,000 vphgpl (h = 1.8 seconds) might be achieved. Also, maximum capacity for a separate left-turn lane was found to be 1,200 vph (h = 3.0 seconds) of green (HRB 1965).

The main conclusions of a study conducted in the 1970's indicate that almost 30 years after Greenshields' findings, more aggressive driving habits and better acceleration performance of vehicles (standard vs. automatic transmissions) had resulted in a start-up lost time considerably lower, 1.1 seconds instead of 3.7 seconds, nevertheless reporting the same value of 2.1 seconds for h (Kunzman 1978)[8].

Left-turn and through lane capacity was another issue in this investigation, which found that by considering intersection width instead of number of lanes in the analysis procedure, the 1965 edition of the HCM underestimates capacities from 13 to 44% in those lanes. Finally, worth mentioning is the simplicity of the methodology used in this study, since it only required from the author to use a stop watch to collect data while merely traveling for about a month through various locations (Kunzman1978)[8].

As a result of the continuing evolution of both driving habits and vehicle performance, values for parameter h have shown a tendency to decrease, meaning higher saturation flow rates. While the 1985 edition of the HCM recommended an h value of 2.0 seconds or a saturation flow rate of 1,800 vphgpl, an update of the same manual in 1994 revised the h value to approximately 1.9 seconds or a saturation flow rate of 1,900 vphgpl; this is the recommended h value to use in 2000 edition of the HCM (TRB 2000).

Methodology:-

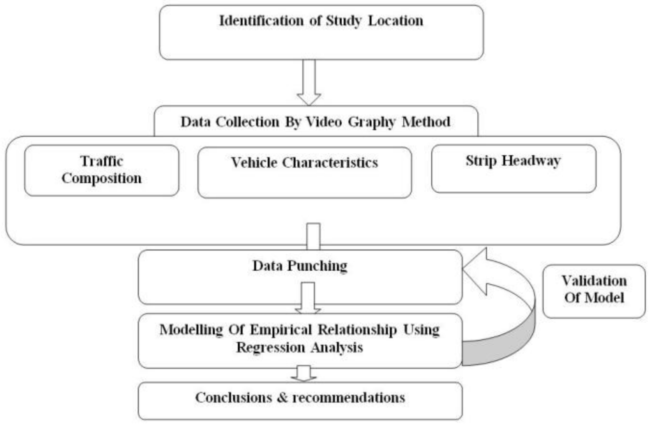


Figure 3.1

Identification Of Study Location

The main aim of the study is to find a relation between discharge headway and other various factors at signalised intersection. So a pilot survey was done through all the signalised intersection of the Srinagar city to indentify intersections suitable for study. After survey, six intersections was finalised as study locations viz. Sanatnagar, Bemina, Lal Chowk, Regal Chowk, Munawarabad& TRC crossing. Among these six locations, two were four legged intersections & the rest four were three legged intersections.

Data Collection By Video Graphic Method

Data collection was done by video recording the traffic movement at six signalized intersections in Srinagar (Jammu and Kashmir), India. For measuring headway values, video camera were mounted in such a way that the view of any vehicle was not severely obstructed by other vehicle. Video camera was mounted on light posts in the vicinity of the intersection that provided a clear view of traffic movements. Video was recorded during the peak periods at the intersections (09:00 to 11:00 in morning & 03:30-06:30 in evening).

DATA COLLECTION & DATA PUNCHING

Data collection was done by video recording the traffic movement at six signalized intersections in Srinagar (Jammu and Kashmir), India. For measuring headway values, video camera were oriented in such a way that the view of any vehicle was not severely obstructed by other vehicle. Video camera was mounted on high rise buildings/light posts in the vicinity of the intersection that provided a clear view of traffic movements. Video was recorded during the peak periods at the intersections.

Data Extraction

Time headway is defined as the difference in time when the front/back of a vehicle crosses a point in the road section and the time when the front/back of the next vehicle crosses the same point. Discharge headway can be defined as the time headway of vehicles that are discharging from an approach to an intersection when the signal is green. Time stamps of different vehicles crossing the stop line were obtained using the K-Lite Kodak and MCME software. Vehicles were identified and then their characteristics were used in analysis like length of vehicle and engine capacity if a vehicle. A reference point is chosen close to the stop line of intersection, with respect to which headway values are to be measured. To get individual vehicle headways, each lane is divided into multiple strips. The width of a strip is approximately equal to the width occupied by a motorcycle. The headways of vehicles in each strip are measured separately. When a vehicle passes this point, the vehicle characteristics and the time stamp is recorded. The recorded data is subsequently post-processed to obtain the discharge headway.

Strip Headway

In India, two wheelers were found to advance through the gaps and move to the head of the queue. The arrangement of vehicles is hap-hazard at the start of green. When the signal turns to green, all these vehicles discharge together side by side very close to each other without any lane discipline. This makes it difficult to measure the headway values of vehicles since there will be more than one vehicle moving simultaneously through the road section. In-order to get a unique headway value for each vehicle, a new approach of strip headway is used for measuring headway values. It is based on dividing the whole road section into several equal longitudinal strips such that one strip width can accommodate only one motor cycle at a time. This ensures that on any given strip the headway is uniquely defined since there is utmost one leading/following vehicle. Thus headway values are measured for each strip separately. As the width of strip is equal to width of two wheelers, other vehicles will be occupying multiple strips at a time which results in multiple headways for same vehicle. Figure 1 depicts such a scenario with h1 and h2 being the headways for the same vehicle. For addressing this problem and obtaining unique headway for each of the vehicles the following procedure is adopted. Firstly the headway data is aggregated based on elapsed green time at a level of 0.1 second. This is done to identify the multiple detections of same vehicles among different strips. Among the multiple values of headway, the smaller value indicates the presence of closer vehicle and it could be assumed that this closer vehicle will be affecting the movement of vehicle of interest more than other vehicle(s). Thus the smallest headway among multiple values is chosen (In figure 1 this value will be h1). Thus the entire data is reduced to data with each vehicle having a unique headway which is used for further analysis. From the available data, higher headway values (values greater than 8 seconds) are ignored and the remaining is used for data analysis. The width of road sections At all the intersect was divided into six sections and the distance was measured from the median.

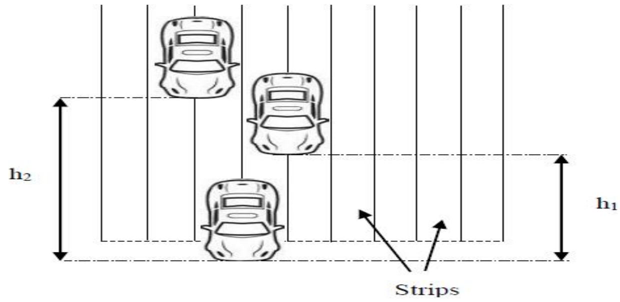


Figure 5.1 Vehicle occupying multiple strips

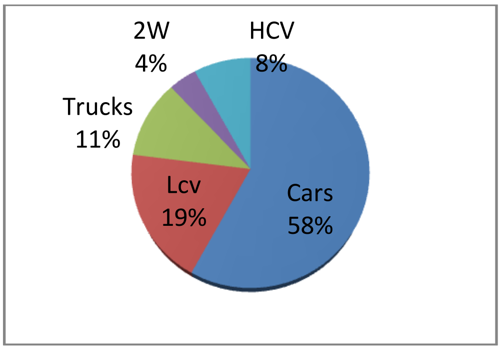
Data Punching

The data that was obtained from the videos of the study locations was converted into an excel file, so that it can be employed for analysis purpose. Some of the entries like time of day were coded and then were employed in analysis.

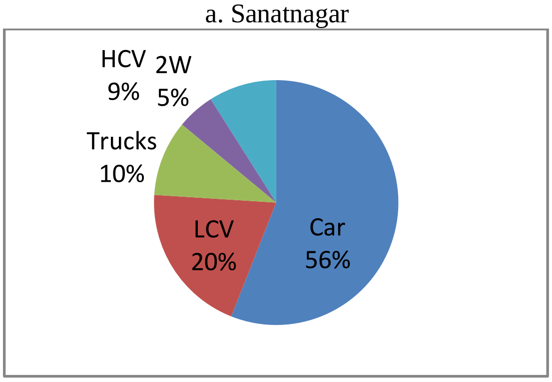
Bearing this in mind, the experimental design of this research addresses time of day,(factor "0" represents AM and factor "1" represents PM) green time and lane factor(it represents the lane section distant from the median for which the data is collected .

III. DATA ANALYSIS & MODELING

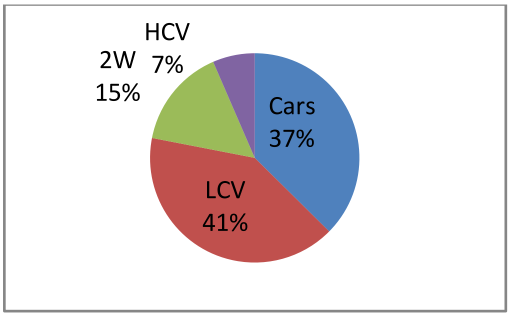
The analysis of the video data revealed that the traffic is heterogeneous with significant number of vehicles in all the vehicle classes considered. Figure 3.2(a,b,c,d,e&f) is a pie chart representing the vehicle composition for the selected study locations.



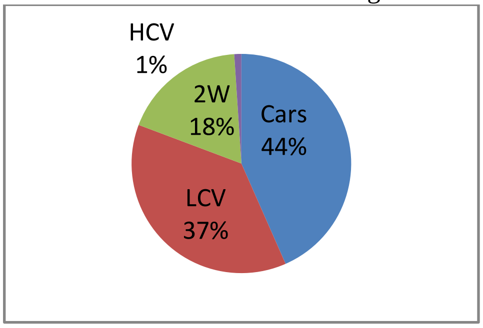
a. Sanatnagar



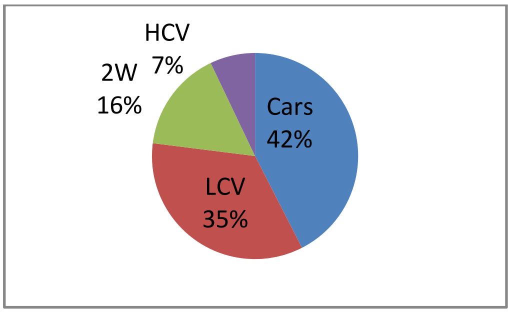
b. Bemina Crossing



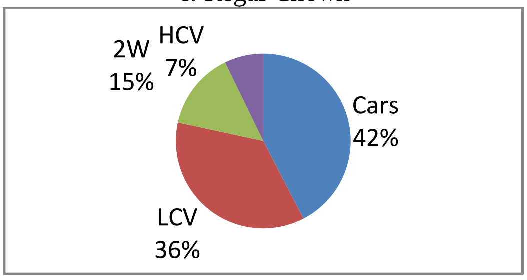
c. Munawarabad Crossing



d. Lal Chowk



e. Regal Chowk



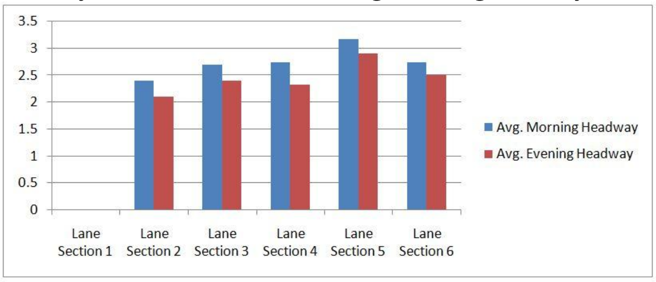
f. TRC Crossing

Pie chart showing vehicle composition at study locations

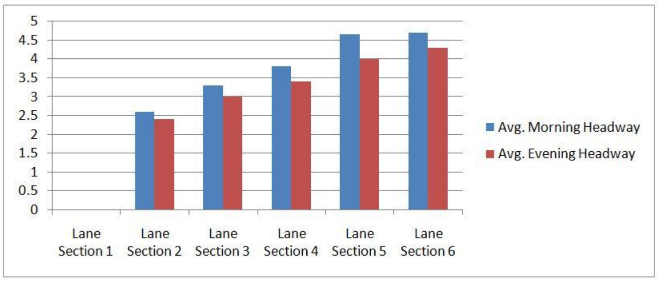
Cars constitute about half of the total vehicles in all locations. Next highest percentage composition is that of LCV followed by Trucks, HCV, and 2ws at Sanatnagar&Bemina intersection while at other intersections trucks are not permeated. The higher composition of cars indicates that cars will have significant impact on the discharging vehicles from signalized intersections. Unlike passenger car only traffic, here two wheelers will move through the available gaps and fill the vacant areas in the queue waiting for discharge. This will lead to change in behaviour for the discharging traffic and their headway values which is being addressed through this study.

Comparison of average headways

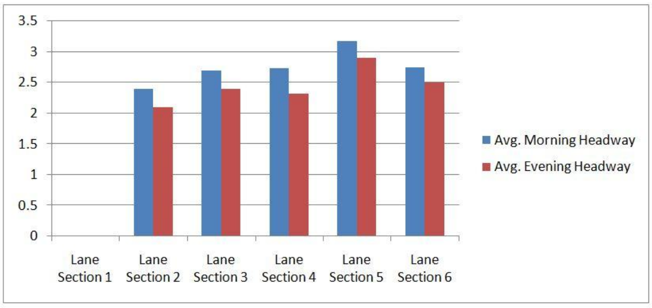
A comparison of average headway at different lane section at morning and evening at different study locations was done. During comparison it was found that average morning headway is more than that of average evening headway.



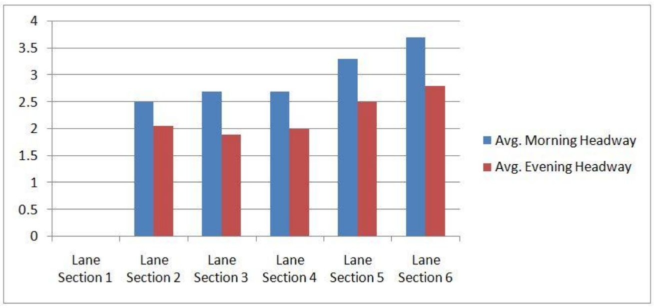
Comparison of average morning & evening headway at Sanatnagar Intersection



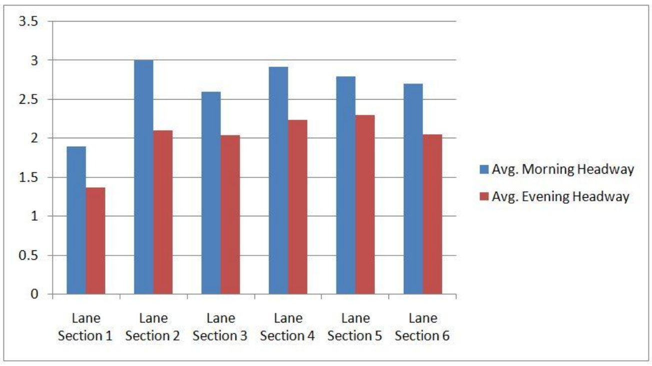
Comparison of average morning & evening headway at Bemina Intersection



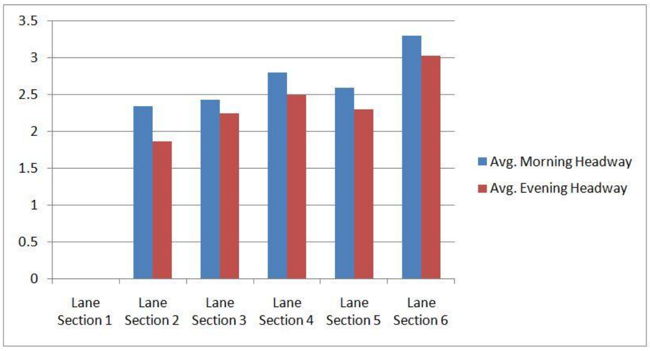
Comparison of average morning & evening headway at Lal Chowk Intersection



Comparison of average morning & evening headway at Munawarabad Intersection



Comparison of average morning & evening headway TRC Intersection



Comparison of average morning & evening headway Regal Chowk Intersection

IV. CONCLUSIONS

This study was carried out to understand discharge headway and the factors affecting it under heterogeneous traffic conditions and develop models to represent discharge headway. Discharge headway values were having variation and were different from homogeneous traffic scenario where the headway tends to follow a constant value after initial four or five vehicles. Vehicle type, lateral position of vehicle in road section, and elapsed green time were identified as the factors affecting discharge headway. Models for computing discharge headway were developed using linear regression and linear mixed regression.

Further research could be done on studying the effect of geometric factors such as grade and curvature, and effect of turning movements on discharge headway. Few other factors such as vehicle composition, driver and pedestrian behaviour, and presence of bus stops near intersection could improve the performance of model.

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